

FLOOD FREQUENCY ANALYSIS FOR BARAK VALLEY IN SOUTH ASSAM

THOKCHOM ARTI DEVI & PARTHASARATHI CHOUDHURY

Department of Civil Engineering National Institute of Technology, Silchar, Assam, India

ABSTRACT

Flood frequency analysis for gauged and ungauged sites in Barak river basin in south Assam are conducted using peak discharge and peak gauge level for the sites. The best fit distribution for the regions were selected based on the results of Z^{DIST} statistics and L-moments ratio diagram from the five extreme value distributions GPD, GLO, GEV, P3 and LP3. Regional flood frequency relationships were established using the selected distribution along with development of growth factors for the sites. A regional flood relationship with the physical characteristics for the sites was established using multiple regressions for the estimation of flood at the ungauged sites with the validity testing of the developed equation.

KEYWORDS: Growth Factors, L-Moments, L-Moments Ratio Diagram, Z^{DIST} Statistics

INTRODUCTION

The observed flood flow in terms of discharges and flood levels for rivers and streams in a drainage area can be used in various engineering works like design of dams and spillways, flood control works, design of bridges and construction of roads and railways and forecasting of flood warning system. Flood frequency analysis is to determine how large a flood of a certain magnitude in terms of discharge or flood level can occur at a given site during the desired return periods. This estimated flood magnitude can give the most vital information during the planning of many engineering and flood related works. Frequency analysis at a single site can give this desired information if the observed data from the site are of sufficient length in comparison to the desired return periods. In case of the sites where the available data are of very short period or data from the sites are not available, at site method of frequency analysis can not be able to give valid and reliable quantile estimation. Regional based frequency analysis is the alternative method of frequency analysis where the available data from the different sites either long or short periods are pooled together so as to augment the site's data for the estimation to a site in a region. L-moments based regional flood frequency analysis approach which is incorporated with the identification of discordant sites along with the testing of regional homogeneity is now the most commonly used method everywhere. L-moments are the linear combination of probability weighted moments (Hosking 1986, 1990). They are less biased for the estimation of parameters of frequency distributions and less effective in the process of frequency analysis during the presence of outliers in the data.

L-moment approach has been used for regional flood frequency analysis (Bardrelin G.H. Hassan et al. 2011 in China, Hussein Maleki-Nezhad et al. 2011 in Iran, Sattar Chavoshi Borujeni et al. 2009 in Malaysia, Ramin Rostami 2013 in Iran, Yeo H. Lim et al. 2009 in USA , Anil Kumar et al. 2012 and Rakesh Kumar et al., 2005 in India). In this study L-moments based regional flood frequency analysis for the gauged and ungauged sites for Barak Valley of Assam, India has been conducted using both annual peak discharge and annual gauge height. So far no such study has been found for flood frequency analysis for the ungauged sites in this valley. Hence, this study has been carried out for the estimation of T-years flood in terms of peak discharge and gauge height for both gauged and ungauged sites in this valley.

The objective of this study is to apply L-moment based approach in regional extreme flood frequency analysis for the gauged and ungauged sites of Barak valley of India and to establish regional mean flood relationship with physical characteristics of the sites using multiple regressions for the estimation of flood at the ungauged sites.

STUDY AREA

This study area lies within 24° N to 26° N and 92° E and 94° E in the southern part of Assam, North East India. This valley comprises of three districts Cachar, Hailakandi and Karimganj of Assam. The annual rainfall of this valley is 2500-3000 mm. Most of the floodplains in Barak valley are in the low-lying areas that get inundated during the monsoon months of June-September by the flood waters of Barak and its tributaries. The Barak river originates from the hills of Manipur and flows touching Mizoram State before it enters the plains of Assam at Lakhipur. After flowing through Silchar it bifurcates near Badarpur into Surma river and Kushiyara river and then it enters into Bangladesh. The principal tributaries of the Barak in India are Jiri, Dhaleshwari (Tlawng), Singla, Longai, Madhura, Sonai (Tuirial), Rukni, Jatinga and Katakhal. The annual peak discharge data from 7 gauged sites and peak gauge level from 8 sites for the period from 1996 to 2010 spread over the valley are collected from Central Water Commission of India, Shillong. The map of the study area is given in Figure 1 and the summary of the gauging sites are listed in Table 1. The steps for L-moment based frequency analysis approach with the index flood procedure are given briefly in the proceeding sections.

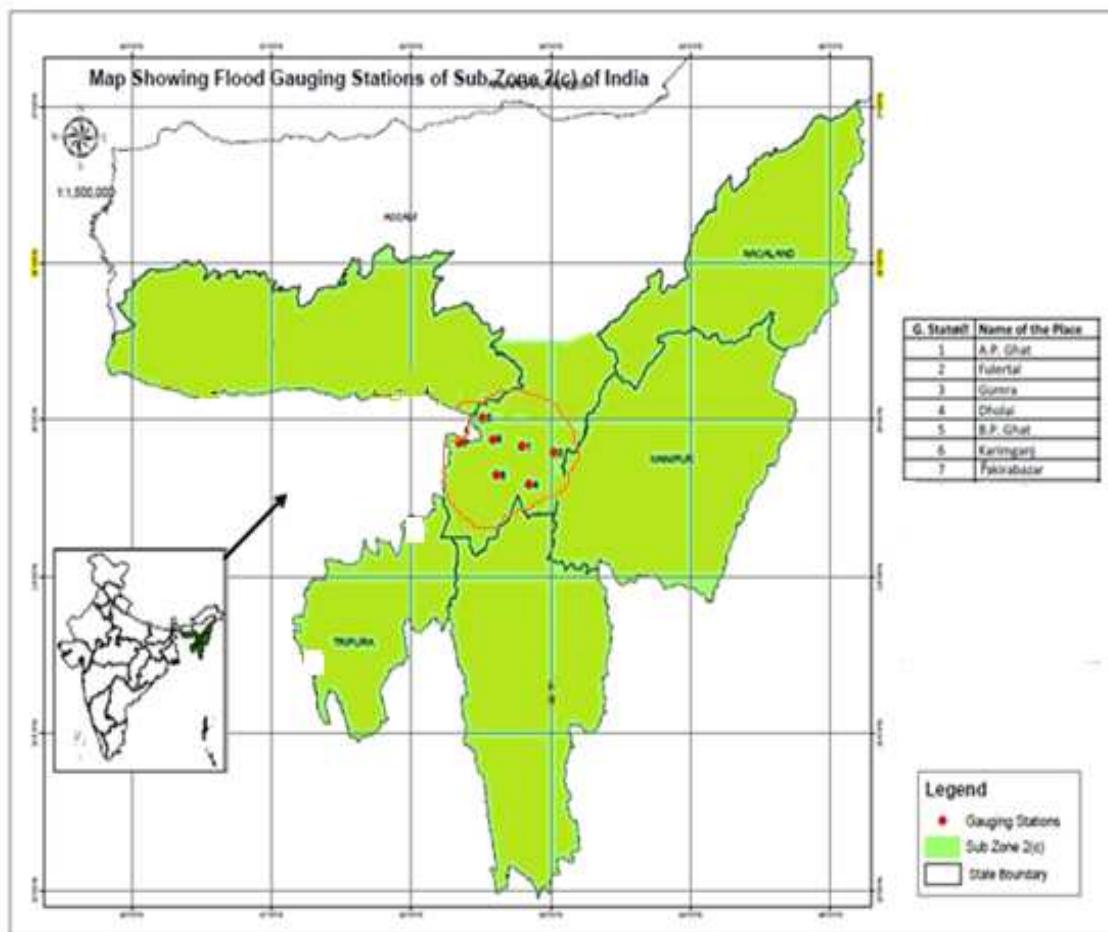


Figure 1: Map of the Study Area (Enclosed in Red Line)

Table 1: Details of the Gauged Sites with the Availability of the Data

Station	River	Latitude	Longitude	Available data		Catchment Area (km ²)
				Discharge	Gauge	
1.A.P.Ghat	Barak	24°49'58"N	92°47'30"E	do	do	18721
2.Fuleratal	Barak	24°47'19"N	93°01'08"E	do	do	14450
3.Gumra	Gumra	25°00'41"N	92°30' 35"E	do	do	2800
4.Dholai	Rukni	24°35'10"N	92°50'32"E	do	do	562
5.B.P.Ghat	Barak	24°52'32"N	92°35'00"E	do	do	24216
6.Karimganj	Kushiyara	24°52'N	92°21'E	-	do	-
7.Fakirabazar	Longai	24°51'06"N	92°20'43"E	do	do	1108
8.Matizuri	Katakhal	24°38'53"N	92°36' 29"E	do	do	7770

L-MOMENT APPROACH

L-moments are linear combinations of probability weighted moments (PWM). The probability weighted moments are calculated from the ranked observations (X_i). Greenwood et al. (1979) defined the probability weighted moments as

$$\beta_r = \frac{1}{N} \sum_{j=i+1}^N (x_j) \frac{(j-1)(j-2)(j-3)\dots(j-1)}{(N-1)(N-2)(N-3)\dots(N-r)} \quad (1)$$

The first four L-moments in terms of probability weighted moments are written by

$$\lambda_1 = \beta_0 \quad (1a)$$

$$\lambda_2 = 2\beta_1 - \beta_0 \quad (1b)$$

$$\lambda_3 = 6\beta_2 - 6\beta_1 + \beta_0 \quad (1c)$$

$$\lambda_4 = 20\beta_3 - 30\beta_2 + 12\beta_1 - \beta_0 \quad (1d)$$

where λ_1 is the L-mean which measures the central tendency, λ_2 is the L-standard deviation and measures the dispersion. The dimensionless L-moment ratios defined by Hosking (1990) are written as

$$L - coefficient of variance: \tau = \frac{\lambda_2}{\lambda_1} \quad (1e)$$

$$L - Skewness: \tau_3 = \frac{\lambda_3}{\lambda_2} \quad (1f)$$

$$L - Kurtosis: \tau_4 = \frac{\lambda_4}{\lambda_2} \quad (1g)$$

The regional weighted values of λ_1 , λ_2 , τ , τ_3 and τ_4 for N sites in a region can be obtained from the following relations

$$\lambda_1^R = \frac{\sum_{j=1}^N (n_j \lambda_j)}{\sum_{j=1}^N (n_j)}; \lambda_2^R = \frac{\sum_{j=1}^N (n_j \lambda_j^2)}{\sum_{j=1}^N (n_j)}; \tau^R = \frac{\sum_{j=1}^N (n_j \tau_j)}{\sum_{j=1}^N (n_j)}; \tau_3^R = \frac{\sum_{j=1}^N (n_j \tau_{3j})}{\sum_{j=1}^N (n_j)}; \tau_4^R = \frac{\sum_{j=1}^N (n_j \tau_{4j})}{\sum_{j=1}^N (n_j)}$$

Where $i = i^{th}$ site and $N =$ number of sites. These regional values of weighted L-moments and their ratios are the basic parameters for L-moments based regional frequency analysis.

DISCORDANCY MEASURE

The aim of the regional frequency analysis is to select the best fit frequency distribution applicable to all the sites over the region. So, the collected data from the sites should be from the same frequency distribution. Discordancy measure is to screen out data from the unusual sites whose sample L-moments are markedly different from other sites. It is measured in terms of L-moments (Hosking & Wallis, 1993) and is defined as

$$D_i = \frac{1}{n} (\mathbf{u}_i - \bar{\mathbf{u}})^T \mathbf{A}^{-1} (\mathbf{u}_i - \bar{\mathbf{u}}) \quad (2)$$

Where $\mathbf{u}_i = (\tau_1, \tau_2, \tau_3)^T$ is a vector containing, τ_1 , τ_2 and τ_3 values of a site i , the superscript T denotes transpose of a matrix or vector; $\bar{\mathbf{u}} = \frac{1}{N} \sum \mathbf{u}_i$ represents the group average and \mathbf{A}^{-1} is the inverse of the covariance matrix \mathbf{A} of \mathbf{u}_i . The elements in \mathbf{A}^{-1} are given by the following relation

$$\mathbf{A} = \frac{1}{N} \sum_{i=1}^N (\mathbf{u}_i - \bar{\mathbf{u}})(\mathbf{u}_i - \bar{\mathbf{u}})^T \quad (3)$$

Where N is the number of sites in the region. The station i is declared as discordant, if its (D_i) value obtained using equation (2) is greater than the critical value. The critical values of (D_i) depend upon the number of sites in the region. For a region having a number of sites ≥ 15 , the critical value is taken as 3 however, if the number of sites is < 15 the critical value can be obtained from the table given by Hosking and Wallis (1993).

The L-moments and their ratios with the discordancy (D_i) for the 7 sites using annual peak discharge data and 8 sites using annual peak gauge level data are given in Table 2 and Table 3. It is observed that there is no discordance site available for both the data. The regional L-moments and their ratios for these sites are in Table 4.

Table 2: L-Moments and Discordancy Values for the Sites (Discharge)

Station	n	λ_1	λ_2	τ	τ_3	τ_4	$D_{critical}$	D_i
1.A.P.Ghat	13	20.60915	0.487051	0.023633	-0.11091	0.191232	2.140 for N = 8	0.6189
2.Fulertal	13	24.83423	0.50981	0.020529	0.108812	0.042471		0.7323
3.Gumra	13	17.65308	0.17218	0.009754	-0.0429	0.031006		1.4521
4.Dholai	13	27.23077	0.328203	0.012053	-0.33857	0.376962		1.7765
5.B.P.Ghat	13	17.51654	0.322052	0.018386	-0.0317	0.276041		0.7103
6.Karimganj	15	15.87467	0.245905	0.01549	0.03803	0.175753		0.2793
7.Fakirabazar	13	17.22039	0.256218	0.014879	0.050554	0.056539		0.4048
8.Matizuri	13	21.81808	0.548269	0.025129	-0.41457	0.08661		2.0254

Table 3: L-Moments and Discordancy Values for the Sites (Gauge Level)

Station	n	λ_1	λ_2	τ	τ_3	τ_4	$D_{critical}$	D_i
1.A.P.Ghat	13	20.60915	0.487051	0.023633	-0.11091	0.191232	2.140 for N = 8	0.6189
2.Fulertal	13	24.83423	0.50981	0.020529	0.108812	0.042471		0.7323
3.Gumra	13	17.65308	0.17218	0.009754	-0.0429	0.031006		1.4521
4.Dholai	13	27.23077	0.328203	0.012053	-0.33857	0.376962		1.7765
5.B.P.Ghat	13	17.51654	0.322052	0.018386	-0.0317	0.276041		0.7103
6.Karimganj	15	15.87467	0.245905	0.01549	0.03803	0.175753		0.2793

Table 3: contd.,

7.Fakirabazar	13	17.22039	0.256218	0.014879	0.050554	0.056539		0.4048
8.Matizuri	13	21.81808	0.548269	0.025129	-0.41457	0.08661		2.0254

Table 4 : Regional L-Moments and their Ratios

Regional L-Moments and Their Ratios	Discharge	Gauge
λ_1^R	2114.0166	20.260273
λ_2^R	239.34528	0.356582
τ^R	0.1324421	0.017443
τ_2^R	0.0581456	-0.090192
τ_4^R	0.1521240	0.1549763

HETEROGENEITY MEASURE (HOSKING and WALLIS, 1997)

The heterogeneity measure estimates the degree of heterogeneity in a group of sites and determines whether the group of sites can be reasonably treated as a homogeneous region. It compares the inter-site variations in sample L-moments for the group of sites with what would be expected of a homogeneous region. A statistic based on the weighted variance of the L-coefficient of variation (L-cv) is derived and heterogeneity measure is defined as

$$H = \frac{V - \mu_V}{\sigma_V} \quad (4)$$

where V = weighted standard deviation of L-cv for the observed data and is given by

$$V = \left[\frac{\sum_{i=1}^N (n_i)(\tau_i - \bar{\tau})^2}{\sum_{i=1}^N (n_i)} \right]^{1/2} \quad (5)$$

Here, n_i = record length for the site ; τ = the L-Cv for the site $i = 1, 2, 3, \dots, N_T^R$ = the weighted group mean L-Cv ; N = no. of sites in the region and μ_V and σ_V are the mean and standard deviation respectively for the weighted standard deviations for the 500 sets of simulated homogeneous regions generated by Monte Carlo simulation using a 4-parameter Kappa distribution (Hosking, 1997).

The quantile function of the distribution is given by

$$x(F) = \xi + \frac{\alpha}{K} \left\{ 1 - \left[\frac{(1-F)^h}{\beta} \right]^K \right\} \quad (6)$$

The parameters of this distribution ξ , α , K and h are estimated using their relationship with regional λ_2^R , τ^R , τ_2^R and τ_4^R values; F is the probability and $x(F)$ is the flood quantiles. The flood quantiles for the different sites are simulated using the quantile function, given in equation (6) from the data.

The criteria for deciding the heterogeneity of a region is as follows

- if $H < 1$, the region is acceptably homogeneous,
- if $1 \leq H \leq 2$, the region is possibly heterogeneous,

- if $H \geq 2$, the region is definitely heterogeneous.

The parameters for Kappa distribution ξ , α , K and h along with the values of V, μ_v , σ_v and H for the 7 and 8 sites are given in Table 5. The H values for the 7 and 8 sites are 0.2515 and -0.4088 respectively. Hence this valley as whole is homogeneous for both the data.

Table 5: Parameters of Kappa Distribution ξ , α , K and h Along with the Values of V, μ_v , σ_v and H

Parameters	For Annual Peak Discharge	For Annual Peak Gauge
h	-0.564199	-0.422399
K	0.157499	0.004699
α	0.029254	0.004415
ξ	0.2088678	0.201074
Homogeneity Measure		
V	0.03883	0.005037
μ_v	0.03858	0.005423
σ_v	0.00994	0.000944
H	0.2515	-0.4088

GOODNESS OF FIT MEASURE

Statistics

The goodness of fit criterion for each of the candidate distributions is carried out by comparing the L-moments of the candidate distributions to the regional average L-moments statistics derived from the regional data. For each of the distributions, the goodness of fit measure (Hosking and Wallis, 1997) is given by

$$Z^{DIST} = \frac{\tau_4^{DIST} - \tau_4^R + \beta_4}{\sigma_4} \quad (7)$$

where τ_4^R = weighted L-kurtosis obtained from the data of a given region.

τ_4^{DIST} = L-kurtosis of the fitted distributions which are derived from their relationship of regional L-kurtosis τ_4^R .

τ_{4sim}^R = weighted L-kurtosis obtained from the simulated data.

$$\beta_4 = \frac{\sum_{i=1}^{N_{sim}} (\tau_{4sim}^R - \tau_4^R)}{N_{sim}} \quad \text{measures bias of weighted } \tau_4^R \text{ with weighted } \tau_{4sim}^R \text{ of the simulated regions and } \sigma_4$$

is computed using the relation

$$\sigma_4 = \left[\frac{1}{(N_{sim}-1)} \left\{ \sum_{i=1}^{N_{sim}} (\tau_{4sim}^R - \tau_4^R)^2 - N_{sim} \beta_4^2 \right\} \right]^{\frac{1}{2}} \quad (8)$$

Here, N_{sim} the number of simulated regional data sets generated using a 4-parameter Kappa distribution. If $|Z^{DIST}|$ obtained by using equation (12) is close to zero the fit is considered to be adequate and reasonable if $|Z^{DIST}| \leq 1.64$. If all the distributions have their $|Z^{DIST}| \leq 1.64$, the one which is closest to zero is selected as the best fit distribution for a region. The $|Z^{DIST}|$ values for both the data are given in Table 6. It is observed that the best fit distribution for both the data are found as LN3.

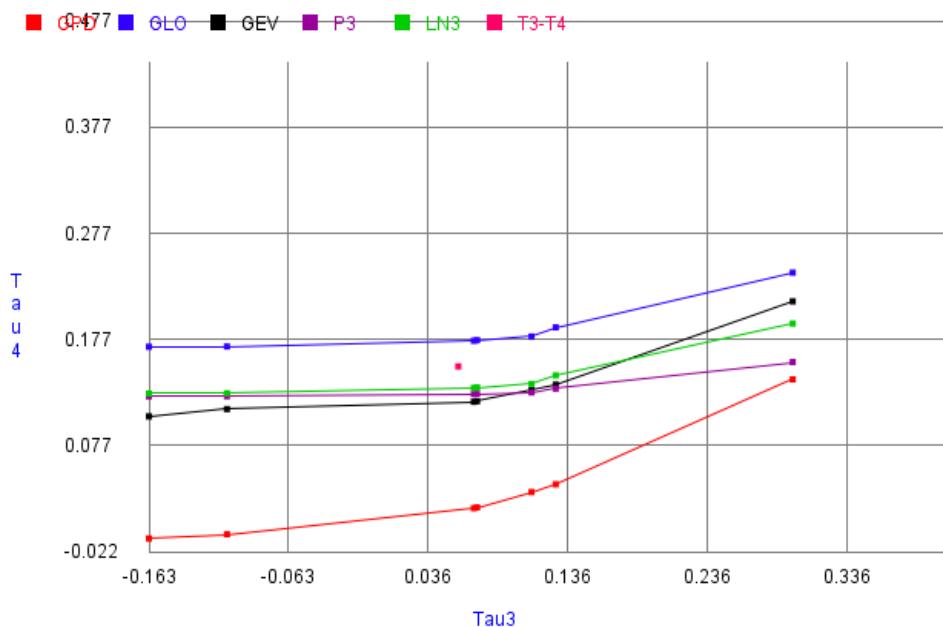
Table 6: Selection of Best Fit Distribution Using $|Z^{\text{DIST}}|$ Statistics

Distribution	$ Z^{\text{DIST}} $ Statistics	L-Moment Ratio Diagram	$ Z^{\text{DIST}} $ Statistics	L-Moment Ratio Diagram
GPD	0.4623		0.4948	
GLO	0.1311		0.1578	
GEV	0.0752		0.0931	
P3	0.0853		0.0649	
LN3	0.0440	LN3	0.0098	LN3

L-MOMENTS RATIO DIAGRAM

L-Moment ratio diagram (Kroll & Vogel, 2002 and Kumar et al, 2003) is another tool commonly used for the selection of the best distribution by comparing its closeness to the regional L-skewness and L-kurtosis. The L-kurtosis (τ_4) for each of the distribution are derived from their relationship of L-skewness (τ_3) for the sites. The L-kurtosis (τ_4) derived for each of the distribution are plotted against L-skewness (τ_3) for the sites and the distribution which is closest to the regional values of (τ_3^R , τ_4^R) is selected as the best fit distribution.

The L-moments ratio diagram for both the data are given in Figure 2 and Figure 3. In this test also the best fit distribution for both the data can be taken as LN3..

**Figure 2: L-Moment Ratio Diagram (Discharge)**

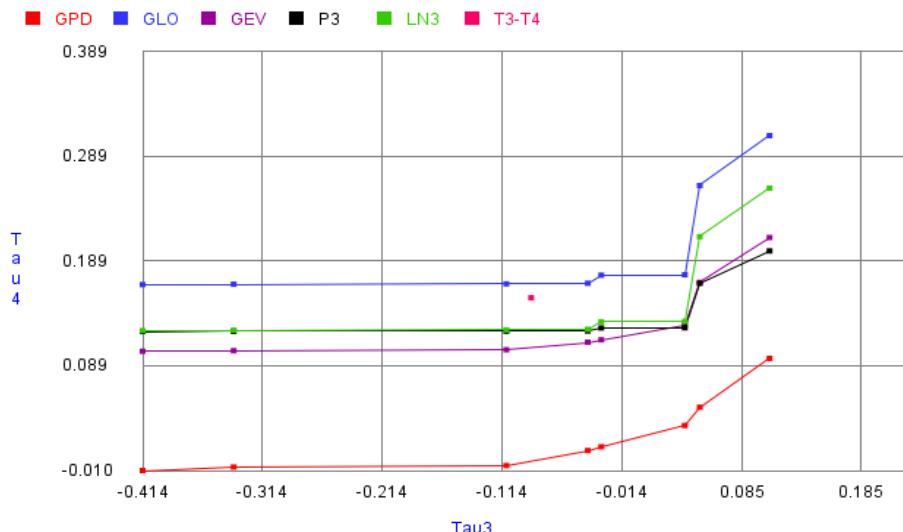


Figure 3: L-Moment Ratio Diagram (Gauge Level)

INDEX FLOOD PROCEDURE

The index flood procedure assumes that in a homogeneous region the frequency distribution at the sites are approximately identical apart from a scale factor (Dalrymple, 1960). For a homogeneous region having N sites, with site i having sample size n_i and observed data Q_{ij} the following relationship given in equation (14) holds good for a site i in the homogeneous region

$$Q_i(F) = \mu_i q(F) \quad (9)$$

where $j = 1, 2, 3, \dots, n_i$ and $i = 1, 2, 3, \dots, N$; $Q_i(F)$, $0 < F < 1$, is the quantile function of the frequency distribution at site i . μ_i is a site-dependent scale factor, called the index flood and is often taken as the at site mean; $q(F)$ = regional growth factor (Dalrymple ,1960)

If, $\bar{\mu}_i$ be the scale factor or at site mean for site i , then the dimensionless rescaled data for site i can be obtained by dividing the observed data Q_{ij} by the at site mean $\bar{\mu}_i = \lambda_1$

$$q_{ij} = \frac{Q_{ij}}{\bar{\mu}_i} = \frac{Q_{ij}}{\lambda_1} \quad (10)$$

Using Equation (15) a new set of rescaled flood data for each of the stations can be obtained. The regional L-moments and their ratios λ_{1s}^R , λ_{2s}^R and τ_{3s}^R of the rescaled data can be determined as done in case of the observed data or it can be taken as $\lambda_{1s}^R = 1.0$, $\tau^R = \frac{\lambda_2^R}{\lambda_1^R} = \frac{\lambda_{1s}^R}{\lambda_{1s}^R} = \lambda_{2s}^R$ as $\lambda_{1s}^R = 1.0$ and $\tau_{3s}^R = \frac{\lambda_{3s}^R}{\lambda_{2s}^R} = \frac{\lambda_3^R}{\lambda_2^R} = \tau_3^R$.

The parameters of the selected distribution can be estimated from their relationships of L-moments and their ratios of the rescaled data. Then the regional growth factor for different return periods can be obtained using equation (11).

$$\frac{Q_T}{F} = \frac{Q_T}{\lambda_1} = Q_i(F) \quad (11)$$

The flood quantiles Q_T for different return periods for the sites in the region can be estimated by multiplying the regional growth factors $q(F)$ by the scale factor or site mean $\bar{\mu}_i = \lambda_1$ as per Equation (11).

REGIONAL GROWTH FACTORS

The best fit distributions for both the data are found as LN3. The growth factors for the valley can be derived from the quantile function of LN3 by applying index flood procedure. The regional values of λ_{15}^R , λ_{25}^R and τ_{25}^R of the rescaled data for both the data and the parameters of the LN3 distributions are in given in Table 7.

The equations for regional growth factors derived from the quantile function of LN3 for the for both discharge and gauge level are given in Equation (12), and Equation (13) respectively.

Table 7: Regional L-Moment And Their Ratios Of Index Flood Procedure With The Parameters Of The Fitted Distributions

L-Moment of the Rescaled Data	Discharge	Gauge
λ_{15}^R	1.0	1.0
$\lambda_{25}^R = \tau^R$	0.132442	0.017443
τ_{25}^R	0.0581456	-0.090192
τ_{45}^R	0.152124	0.154976
Parameters of LN3 distribution		
ξ	0.98606	0.9972
α	0.23321	0.03049
K	-0.11909	0.18494

DISCHARGE DATA

$$= -0.97212 + 0.382025 \quad \text{Eq. 0.11909} \quad (12)$$

GAUGE LEVEL DATA

$$\frac{Q_T}{P} = -0.97212 + 0.382025 \quad \text{Eq. 0.11909} \quad (13)$$

The regional growth factors for different return periods for both discharge and gauge level is given in Table 8. The estimated flood in terms of discharge and gauge level for different return periods for sites in the regions A and B are given in Table 9 and Table10 respectively.

Table 8: Regional Growth Factors

Data	Growth Factor	Return Periods									
		2	5	10	15	20	30	40	50	75	100
Discharge	$\frac{Q_T}{P}$	0.9937	1.0376	1.0646	1.0793	1.0893	1.1030	1.1124	1.1196	1.1323	1.1411
Gauge	$\frac{Q_T}{P}$	0.9972	1.0209	1.0320	1.0372	1.0404	1.0446	1.0473	1.0493	1.0526	1.0548

Table 9: Estimation of Flood Discharges for Different Return Periods

Station	2	5	10	15	20	30	40	50	75	100
1. A.P. Ghat	3611.31	4366.82	4793.83	5015.03	5163.35	5361.84	5496.98	5598.79	5777.87	5900.92
2. Fulertal	3908.24	4725.87	5188	5427.38	5587.9	5802.71	5948.96	6059.14	6252.95	6386.11
3. Gumra	168.26	203.46	223.35	233.66	240.57	249.82	256.12	260.86	269.2	274.94
4. Dholai	301.01	363.98	399.57	418.01	430.37	446.92	458.18	466.67	481.59	491.85
5. B.P. Ghat	4995.28	6040.33	6630.99	6936.96	7142.12	7416.68	7603.6	7744.43	7992.14	8162.35
6. Fakirabazar	395.66	478.44	525.22	549.46	565.71	587.46	602.26	613.42	633.04	646.52
7. Matizuri	1296.14	1567.3	1720.56	1799.95	1853.19	1924.43	1972.93	2009.47	2073.74	2117.91

Table 10: Estimation of Flood Gauge Level for Different Return Periods

Station	2	5	10	15	20	30	40	50	75	100
1. A.P. Ghat	20.54	21.03	21.26	21.37	21.43	21.52	21.57	21.62	21.68	21.73
2. Fulertal	24.76	25.35	25.62	25.75	25.83	25.94	26	26.05	26.14	26.19
3. Gumra	17.6	18.02	18.21	18.31	18.36	18.44	18.48	18.52	18.58	18.62
4. Dholai	27.15	27.8	28.1	28.24	28.33	28.44	28.52	28.57	28.66	28.72
5. B.P. Ghat	17.46	17.88	18.07	18.16	18.22	18.29	18.34	18.37	18.43	18.47
6. Fakirabazar	15.83	16.2	16.38	16.46	16.51	16.58	16.62	16.65	16.7	16.74
7. Matizuri	17.17	17.58	17.77	17.86	17.92	17.99	18.03	18.07	18.13	18.16
8. Matizuri	21.75	22.27	22.51	22.62	22.69	22.78	22.84	22.89	22.96	23.01

ESTIMATION OF FLOOD FOR THE UNGAUGED SITES

The peak flood in terms of discharge and gauge level at the ungauged sites of this valley is estimated in order to give probable information about flood which may be used in various engineering works. Multiple regression equation (14) is developed by relating mean discharge flood with channel width at the gauging site, elevation and catchment area for the sites for the estimation of mean annual peak discharge flood. The multiple regression equation (15) is also developed by relating mean gauge level with channel width at the gauging site, and elevation in order to estimate mean peak flood level for the sites. The results of the regression equations are validated using chi-square test and site characteristics of the one retained sites. The critical values for the chi-square test between the observed and estimated flood quantiles are much less than the critical value of 12.592 at 5% significance level with 6 degrees of freedom and 14.067 at 5% significance level with 7 degrees of freedom for both the data respectively. Hence this shows that there is no significant difference between the estimated and observed values. The estimated annual peak discharge means for the sites using equations (14) and (15) are given in Table 11 and Table 12.

$$\bar{q} = e^{-11.7120} \cdot (Ch)^{-1.1969} \cdot (Elev.)^{3.8413} \cdot (A)^{0.8580} \quad (14)$$

$$\bar{h} = e^{0.8439} \cdot (Ch)^{0.0914} \cdot (Elev.)^{0.5620} \quad (15)$$

Table 11: Estimation of Flood Discharges for Ungaged Sites

Station	Channel (Ch)	Elevation (E)	Area(A)	Obs.(O)	ln (ch)	ln(E)	ln(A)	ln(Q)	Est.(E)	$\chi^2 = \frac{\sum(O-E)^2}{E}$
1.A.P. Ghat	146.4	19.2	18721	3662.21	4.9863	2.9549	9.8374	8.2058	3563.26	2.7478
2.Fulertal	165.35	31.39	14450	3963.33	5.1081	3.4465	9.5784	8.2848	4073.93	3.0026
4.Dholai	34.52	33.22	562	305.25	3.5415	3.5032	6.3315	5.7211	296.97	0.2309
5.B.P. Ghat	195.24	19.81	24216	5065.69	5.2742	2.9862	10.0948	8.5302	5017.64	0.4602
6.Fakira Bazar	46.37	17.98	1108	401.24	3.8367	2.8893	7.0103	5.9946	412.57	0.3110
7. Matizuri	55.47	29.26	7770	1314.41	4.0158	3.3762	8.958	7.1811	1325.19	0.0876
χ^2 Chi -Square										6.8401
3. Gumra	7.56	32.3	2800	170.63	2.0229	3.4751	7.9374	5.1395	193.14	

Table 12: Estimation of Flood Gauge Levels for Ungaged Sites

Station	Channel (Ch)	Elevation (E)	Obs.(H)	Ln(ch)	P3	Est .(H)	$\chi^2 = \frac{\sum(O-E)^2}{E}$
1.A.P.Ghat	19.2	20.6	4.9863	2.9549	3.0253	19.3	0.0870
2.Fulertal	31.39	24.83	5.1434	3.4465	3.2121	25.81	0.0375
3.Gumra	32.3	17.65	2.0229	3.4751	2.8707	19.72	0.2179
4.Dholai	33.22	27.23	3.5415	3.5032	3.3043	23.02	0.7699
5.B.P.Ghat	19.81	17.51	5.2364	2.9862	2.8628	20.1	0.3339
6.Karimganj	14.02	15.87	4.4667	2.6405	2.7644	15.43	0.0127
7.Fakirabazar	17.98	17.22	3.8367	2.8893	2.8461	16.75	0.0132
χ^2 Chi -Square							1.4721
8.Matizuri	29.26	21.81	4.0158	3.3762	3.0824	22.38	0.0148

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